Attorney Docket No.: 021316-000100US

PATENT APPLICATION

SYSTEM AND METHOD FOR DELIVERING REACTIVE FLUIDS TO REMOTE APPLICATION SITES

Inventors: JAMES L. BIRDSALL, a citizen of the United States of America, residing at:
42 El Toyonal, Orinda, California 94563

DAVID H. JOHNSON, a citizen of the United States of America, residing at:
56 Jessica Court, Alamo, California 94507

Assignee: NeoPoxy Corporation,
6805 Sierra Court, Suite A
Dublin, California 94568
a corporation of the state of California

Prepared by: M. Henry Heines
TOWNSEND and TOWNSEND and CREW LLP
Two Embarcadero Center, 8th Floor
San Francisco, California 94111-3834
Tel: 415-576-0200

AS FILED IN THE U.S.P.T.O.: December 27, 2001

SYSTEM AND METHOD FOR DELIVERING REACTIVE FLUIDS TO REMOTE APPLICATION SITES

BACKGROUND OF THE INVENTION

1. Field of the Invention

[01] This invention resides in the fields of fluid transport systems for supplying multiple materials to remote locations at controlled flow rates and flow rate ratios.

2. Description of the Prior Art

[02] At many construction sites and various types of commercial operations, two or more fluids must be delivered to remote locations separately and yet at controlled flow rates or flow rate ratios. Examples of these operations are repairs of underground pipes by either applying a lining to the inner surface of a pipe or grouting a fissure in the pipe wall. Further examples are supplying liquid or fluidized materials to buildings or construction sites, such as bridges, parking structures, and building foundations, at locations that do not have direct access. Still further examples are supplying materials to mines, manholes, underground tanks or reservoirs, underseas locations, and dams. Examples of materials that must be supplied separately and in closely controlled proportions are reactive components, where premature reaction must to be avoided and reaction stoichiometry maintained. Polymer systems, such as epoxies, polyurethanes, polyureas and polyacrylamides, are prominent examples.

[03] Underground pipes for the transport of water, sewage, or drainage are an illustrative example. These pipes are susceptible to deterioration due to corrosion, organic growth, root infiltration, traffic loading, ground movement, and general degradation. This degradation causes obstructions in the flow through the pipe and in some cases leads to collapse of the pipe. A degraded sewer pipe, for example, may cause sewage to leak out and contaminate both ground water and soil formations, or it may cause ground water to infiltrate and thereby unnecessarily increase flow to a treatment plant.

[04] Sewer pipes are very costly to replace and replacement often entails significant above-ground disruptions. To avoid these disruptions, methods have been developed for sewer pipe repair that do not involve removing the pipe from the ground or digging a trench, but instead involve using remotely controlled methods to apply a lining to the interior wall of the pipe. One method of in-place lining involves inserting a soft, flexible tubular liner that includes a curable resin into the pipe. Once inserted, the liner is pressurized with fluid or air to press the liner against the pipe wall where it is allowed to cure. The procedure is an awkward one, since the uncured liner tube cannot be manipulated inside the pipe, and there is less than full assurance that the tube is properly placed or evenly pressurized along its entire length to achieve the desired degree of repair.

[05] An alternative method for applying a lining by remote means is to insert a long flexible conduit into the pipe, and spray a resin out through a nozzle at the end of the pipe to coat the inside wall of the pipe, allowing the resin to cure in place after it is sprayed. Many resins applied in this manner are two-component resins such as epoxies, polyurethanes, and polyureas. For maximum effect, the two components of these reactive resin systems must be kept separate until they reach the point of application inside the pipe, and accordingly they must be pumped separately. Current pumping methods for this type of application use mechanically slaved reciprocating proportioning pumps.

[06] One difficulty with two-component reactive resin systems and multi-component reactive systems in general is that the various components react at a specific stoichiometric ratio, and any excess of one of the components results in the presence of unreacted material after the resin is cured. In addition to the inefficiency of feeding material that does not react, the unreacted components are retained in the resin and degrade the quality of the lining. In addition, the unreacted components may slowly leach out of the lining and contaminate the fluids passing through the pipe. For maximum efficiency, lining quality, and sometimes safety, therefore, it is important to maintain the correct stoichiometric ratio of the two components at the point of application.

[07] When proportioning pumps are used, acceptable control and steadiness of flow ratios can only be obtained at pump rates that are well below the pump capacity, since most of the pulsing that is characteristic of these pumps can be eliminated by the accumulated pressure in the flexible conduit between the pumps and the nozzle and by the spray nozzle itself before the next stroke is completed. The problem is particularly acute when there is little or no back pressure at the distal end of the conduit. Typical capacities of proportioning pumps however are under 3 gallons per minute (0.7 cubic meter per hour). Thus, to minimize pulsing with

these pumps, the pump rate must be limited to about 1 gallon per minute (0.23 cubic meter per hour). This is acceptable for small bore pipes but not for the large bore pipes that are typical in many sewer systems and other water-transport systems. Also, proportioning pumps have limited variability in ratio adjustment, since they are governed primarily by pump cylinder ratios.

[08] Another difficulty with two-component reactive systems is that the flow rates of the components can vary with differences in viscosity, temperature, and other factors affecting the component densities, as well as the degree of wear on the pump and the condition of the hoses serving as conduits. Flow rates are most commonly measured by pressure differential, and the viscosity, temperature, and other factors listed above can affect pressure differentials along the flow path and therefore give readings unrelated to changes in mass flow.

SUMMARY OF THE INVENTION

[09] It has now been discovered that multiple components that are to be placed in contact only at a remote location can be delivered to that location with both a high degree of ratio control over flow rates of the components and wide range of flow rates including high volumetric flow rates. This discovery is useful for the *in situ* application of pipe linings formed from a multi-component lining material and for any site-directed location including the construction sites, underground sites, underseas sites, and other remote locations listed above. This result is achieved by a system which includes separate crescent internal gear pumps for the individual reactive components and a control loop which includes flowmeters measuring the mass flow rate of each component and an automatic controller that compares the measured rates with a preselected value(s) and generates signals to adjust the pump speeds to correct for deviations from the preselected value(s). The flows that are controlled in this manner are conveyed to the remote location, whether it be a pipe interior, an inaccessible contruction site or any of the other applications listed above, by separate conduits, preferably a multi-lumen cable that contains separate lumens for the individual components. The components are combined at the distal end of the conduits where they are combined and deposited, dispensed, or dispersed at the site of interest.

[10] The crescent internal gear pumps provide a smooth flow without pulsing, and continuous variability in the flow ratio to allow continuous adjustments to the flows to correct for very small deviations from the desired ratio without imposing equipment-based limitations on the adjustments. The mass flowmeters allow the system to provide ratio

control by mass rather than by pressure differential. Mass flow control permits continuous and accurate maintenance of the reaction stoichiometry and avoids adjustments based on factors that affect component density or pressure drop rather than mass.

[11] In certain applications, system components in addition to the primary reacting components may be included for purposes of modifying the character of the material being deposited, for example in the case of pipe linings the physical or chemical characteristics of the lining, or for accelerating the rate of reaction, or generally for modifying any parameter or feature of the process. The systems of the present invention can accommodate the optional inclusion of these additional components by allowing them to be individually pumped and conveyed to the site of application at flow rates controlled in the same manner as the primary components.

[12] These and other features, advantages, and embodiments of the invention are described in more detail in the succeeding sections of this specification.

BRIEF DESCRIPTION OF THE DRAWINGS

[13] FIG. **1** is a process flow diagram of a pipe lining system in accordance with this invention.

[14] FIG. **2** is a cross section of a multi-lumen cable suitable for use in transporting the individual components of the pipe lining composition through an underground pipe.

DETAILED DESCRIPTION OF THE INVENTION AND PREFERRED EMBODIMENTS

[15] A crescent internal gear pump has two circular gears, i.e., an outer gear with inward-extending teeth that meshes with outward-extending teeth of an inner gear, both gears rotating within a common housing but on different parallel axes that place the gears in eccentric relation, leaving a crescent-shaped space between them. Much of the crescent-shaped space is occupied by a crescent-shaped insert that provides a close clearance between itself and the tips of the gear teeth. Either gear may serve as the drive gear, although preferably the inner gear is the drive gear. The gear teeth create voids as they come out of mesh, expanding as the gears rotate to create a suction to draw fluid into the space between the gears and hence into the pump. As the gears come back into mesh, the volumes around the teeth are reduced, thereby increasing the pressure and forcing the fluid out through a discharge port. The flow rate is thus determined by the rotation speed of the gears. Typical

crescent internal gear pumps have thirteen teeth on the inner gear and seventeen teeth on the outer gear, operate at a speed of from about 400 to about 6,000 rpm, preferably from about 700 rpm to about 3,600 rpm, with a displacement per revolution of from about 0.3 cubic inch to about 15 cubic inches (about 0.005 liter to about 0.25 liter). Preferred pumps are those having a continuous rated pressure ranging from about 2,000 psi to about 6,000 psi and peak pressures of from about 3,000 psi to about 5,000 psi. Either single-stage or multiple-stage (typically dual-stage) pumps can be used. Crescent internal gear pumps are disclosed in United States Patents Nos. 3,491,698 (Truninger, inventor, issued January 26, 1970), 5,360,325 (Henry et al., inventors, U.S. Navy, assignee, issued November 1, 1994), and 5,605,451 (Saitoh, inventor, Tokyo Sintered Metal Company Limited, assignee, issued February 25, 1997). The disclosures in each of these patents are incorporated herein by reference. Crescent internal gear pumps are commercially available from pump suppliers such as Imo Pump of Monroe, North Carolina, USA.

[16] Each crescent internal gear pump can be driven by a motor with a conventional variable or adjustable frequency drive. Frequency drives of this type are readily available from commercial suppliers, such as for example Fuji Electric Corp. of America, Saddle Brook, New Jersey, USA. Pumps designed specifically for frequency drive motors are available from GE Industrial Systems, Plainville, Connecticut, USA, and Baldor Electric Company, Fort Smith, Arkansas, USA. A typical frequency drive is Model AF-300 G11, available from Fuji Electric Corp. and from GE Industrial Systems.

[17] Mass flow rates are measured in accordance with this invention by the use of flowmeters of known constructions and operating principles that measure mass flow rate rather than simple volumetric or linear flow rate and are not significantly affected by factors that may affect pressure drop or other flow parameters independently of the mass flow rate. Mass flowmeters of various types are known and commercially available, any of which can be used in the practice of this invention. Included among these types of flowmeters are thermal flowmeters, electronic flowmeters, and Coriolis-type flowmeters. Coriolis-type flowmeters are preferred.

[18] In Coriolis-type flowmeters, the fluid whose mass flow rate is to be measured passes through a tube that is oscillating due to the imposition of a sine-wave voltage from an electromagnetic drive. The flowing fluid imposes a Coriolis force on the tube that modifies the oscillation, typically causing points along the tube to oscillate out of phase with other points along the tube. The magnitude of the difference is directly related to the mass flow through the tube and is used as a means of measuring the mass flow. Coriolis-type

flowmeters are disclosed in the literature, for example in United States Patents Nos. 4,891,991 (Mattar et al., inventors, issued January 9, 1990), 4,911,020 (Thompson, inventor, issued March 27, 1990), 5,048, 350 (Hussain et al., inventors, issued September 17, 1991), and 5,054,326 (Mattar, inventor, issued October 8, 1991), all assigned to The Foxboro Company, Foxboro, Massachusetts, USA, and United States Patents Nos. 4,491,025 (Smith et al., inventors, issued January 1, 1985) and Re. 31,450 (Smith et al., inventors, issued February 11, 1982), both assigned to Micro Motion, Inc., Boulder Colorado, USA. The disclosures in each of the patents in this paragraph are incorporated herein by reference. Coriolis-type mass flowmeters are commercially available from instrumentation suppliers such as Endress+Hauser, Inc., Greenwood, Indiana, USA, and Yokogawa Corporation of America, Newnan, Georgia, USA.

[19] Automated process control can be achieved by conventional software that is readily programmed by anyone skilled in the use of computer control of chemical processes. One example of software that can be used effectively is LabVIEW process control software on a personal computer, for example an IBM compatible computer.

[20] Transport of the individual reactive components to the site of application, which may be a pipe interior or other remote or otherwise inaccessible location, can be achieved by the use of conventional fluid flow conduits that keep the components separate until they reach the site of application. In the case of pipe interiors, the preferred conduits are those that can be drawn through the pipe at a controlled speed by a remote drive so that a coating of a desired thickness can be deposited along the pipe wall. The individual components are combined at the distal terminus of the conduits where they are conveyed outward as a mixture to be deposited at the site of application and to react with each other at the same time. Independent conduits can be used, although it is preferred to use a multi-lumen cable (commonly referred to in the industry as an "umbilical cable") serving as a feeder line for the components. Preferred multi-lumen cables contain lumens for the components of the lining composition and additional lumens for temperature control, such as for example the circulation of heated water or any other liquid heat transfer medium. Further lumens can also be included to serve additional purposes such as supplying electric power to a powered application head at the cable terminus, accommodating temperature and pressure transducers, receiving and transmitting signals from the temperature and pressure transducers, providing signal transmission such as video signals to permit imaging of the locus of application for viewing on an distant (for example, above-ground) monitor, providing control of robotic implements at the cable terminus, and supplying power to a light source to enhance the video transmitter.

[21] The applicator at the distal terminus of the multi-lumen cable can be any device that combines the components and directs them to the desired site of application. In embodiments of the invention in which pipe linings are applied, the applicator can be a spray nozzle, either airless or one that is air-assisted, a fanning device, a centrifugal casting device, or any other ejection means that directs the mixture evenly around the circumference of the pipe. For applications of this invention where 360-degree application is needed, a rotating sprayer is preferred, particularly one having two rotors that rotate simultaneously in opposite directions. In pipe interior applications, this will avoid or minimize any coating thickness variations that might otherwise form around protrusions or other irregularities in the surface of the pipe wall. The sprayer can be mounted on a trolley, which term is used herein to denote any movable support that can be caused to travel along the length of the pipe with minimal resistance and that holds the sprayer at approximately the center of the pipe so that the sprayer travels along the pipe axis as the conduit is being drawn through the pipe.

[22] The present invention applies to the deposition of compositions that are formed by the reaction of two or more components that react upon contact and must therefore be kept out of contact to prevent premature reaction until they reach the point of application. This description applies to many polymers. Examples are two-component polymer systems including, but not limited to, epoxies, polyurethanes, polyureas, and polyesters. Epoxies are of particular interest, particularly for pipe lining applications. For optimum performance, the individual components are maintained at a temperature within a preselected range to control viscosity and maintain a uniform consistency.

[23] Systems in accordance with this invention can also accommodate the inclusion of additional pumps and transport lines to supply additional components, either to a mixing point aboveground or through separate lumens in the multi-lumen cable to the site of application. For polymer systems, such additional components can include modifiers such as gelling agents, accelerators, catalysts, and diluents, or any such components that can be used to control the reaction rate or the physical or chemical characteristics of the polymer coating.

[24] While the invention can be implemented in many different configurations and arrangements, the system depicted in FIG. **1** represents a pipe lining system and is offered for purposes of illustration. In this system, two components of a two-component polymer are stored in separate conditioning tanks **11** and **12**, each of which is a jacketed vessel whose jackets are supplied with heated water from a boiler **13** from which the heated water is conveyed to the jackets by individual water pumps **14, 15**. The vessels may also be blanketed with inert gas. The two components that form the polymer are drawn from the conditioning

tanks by preliminary pumps **16**, **17**, which in this example are conventional three-screw pumps. Suitable examples are commercially available from Imo Pump and other pump suppliers. The screw pumps circulate the components through the conditioning tanks by way of recirculation loops **18**, **19**.

[25] Streams of each component are then drawn from the recirculation lines by crescent internal gear pumps **21**, **22** which feed the components to individual lumens in the multi-lumen or "umbilical" cable **23**. The mass flow rates produced by the crescent internal gear pumps are detected by individual Coriolis-type flowmeters **24**, **25**. Three-way valves **26**, **27** on the output lines of each of the crescent internal gear pumps allow the pump outputs to be directed either back to the recirculation loops **18**, **19** or to the umbilical cable.

[26] The above-ground portion of the umbilical cable **23** is mounted on a reel **28** and is drawn to and from the reel by a linear cable traction device **29** which controls the linear velocity of the cable. The temperature of the cable is controlled by heated water supplied separately from the boiler **13** by a water pump **30**. As an alternative, the cable temperature can be controlled by an electric heater (not shown) extending the length of the cable. At the distal end of the umbilical cable are a video camera **34**, a static or dynamic mixer **31** and the applicator head **32** mounted on a trolley **33**. A video camera **34** is also included to permit observation of the pipe interior prior to and during the coating process.

[27] A process logic controller **41** receives signals from the mass flowmeters **24**, **25** and from various data collection points on the system, such as thermocouples, pressure transducers, cable speed indicators, and liquid level indicators (which are not shown in the drawing), and sends signals to the various components such as the crescent internal gear pumps and the linear cable traction device to control the process parameters associated with these components. As noted above, additional feed lines for additional components can be added for inclusion in the umbilical cord or for mixing with the system components prior to entering the umbilical cord or at any point along the process flow lines shown in the diagram.

[28] FIG. **2** depicts an example of an umbilical (or multi-lumen) cable **51** suitable for transport of a two-component reactive polymer such as an epoxy in the practice of this invention. The cross section shown in the figure shows that the cable includes an outer sheath **52** consisting of a braided sleeve embedded in a polymer. Two lumens **53**, **54** are included for the transport of the individual components of the lining composition. Additional lumens **55**, **56** are included for the circulation of heated water. These are closed lumens joined at the distal end, one for inflow and the other for return. The remaining lumens are occupied by power lines, sensor lines, controller lines, and video cables. Additional flow

lumens can be added for the transport of modifiers or other additives to the polymer composition to be applied.

The foregoing descriptions are offered primarily for purposes of illustration. Further variations and modifications that still embody the basic elements of this invention will be readily apparent to those skilled in the art and are included within the scope of the invention.